

# A Crucial Test for Einstein's Special Theory of Relativity Against the Lorentz-Poincaré Ether Theory of Relativity

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A crucial experiment is proposed which should decide between Einstein's interpretation of the Lorentz transformations, where the relativistic effects are explained as the result of space-time transformations, and the alternative interpretation by Lorentz and Poincaré, where all the same effects are explained by real physical deformations of bodies in absolute motion through an ether. To break the interaction symmetry with the ether, suitable experiments must involve rapid rotation to violate the relativistic Born rigid body motion criterion. However, if the body-deformation is governed by regular elastic waves, relativity-violating effects are very small with attainable rotational velocities and are therefore probably unobservable. An exceptional situation exists if the deformation is governed by bending waves. In this case, relativity-violating effects would manifest themselves by a very large resonance, greatly amplifying an otherwise minute effect.

Even though not widely known, there is a mathematically equivalent, from Einstein's interpretation quite different, interpretation of the Lorentz transformations by Lorentz and Poincaré [1, 2, 3]. In it the Lorentz transformations, and all the effects derived from them, are understood as the result of real physical deformations of bodies in absolute motion through a substratum (ether). Poincaré in particular showed, that the theory of relativity can solely be derived from the Fitzgerald-Lorentz contraction effect, using the same clock synchronization convention by reflected light signals also used by Einstein. According to Poincaré, the clock synchronization convention precludes any measurement of the one-way velocity of light. In Einstein's interpretation the velocity of light is isotropic in all inertial reference systems, whereas Lorentz and Poincaré say it is only isotropic in a reference system at rest with the ether but anisotropic in all other inertial reference systems. Poincaré shows that with the change in all lengths by the contraction effect, the average to and fro velocity of light, and which is the only one measurable, turns out to be constant and equal to  $c$  for all inertial reference systems, not just the one at rest with the ether. The clock retardation effect in this alternative interpretation of relativity is understood by the plausible assumption that all physical clocks, and which are held together by electromagnetic

forces, behave like light clocks. For a light clock, consisting of a rod with mirrors at its two ends, in between which a light signal is reflected back and forth, the clock retardation effect is there explained as resulting from both the anisotropic light propagation and rod contraction effect. The relativistic phase shift in time finally, is explained by the definition of simultaneity through clock synchronization by reflected light signals. In this alternative theory the principle of relativity is a derived consequence of the contraction effect (Poincaré, 1904) rather than a postulate (Einstein, 1905).

In a further crucial step taken by Lorentz [4] it was shown that the contraction effect can be derived by the electromagnetic interaction of solid bodies with the ether. Lorentz therefore succeeded in deriving special relativity from known physical principles. The derivation however, was only valid for bodies in a static equilibrium. It therefore meant, that a finite time would be needed for the bodily deformations to take place, and which would have to be determined by the velocity and dissipation of deformation waves within the body. For shorter times the Lorentz-transformations would be violated.

The description of the relativistic effects by Lorentz and Poincaré, still adhering to the concept of an ether, is very much in opposition to Einstein, who says the contraction and time dilation effects are purely relativistic, by which is meant that they result from a transformation of space and time, and

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are therefore instantaneous. Through the discovery of the microwave background radiation the question for the existence of an ether, presumably at rest with this radiation, has in recent years gained new interest, [5] and the search for novel experiments to test the ether hypothesis appears to be highly desirable.

Experiments suitable to exhibit relativity-violating effects must involve bodies in a state of rapid acceleration. Only there can a finite time for the contraction to take place be observed. However, for relativity-violating experiments accelerated motions must be chosen which cannot be performed as relativistic Born rigid body motions. A Born rigid body motion [6], is one which does not produce stresses in the body during its acceleration, and a relativistic Born rigid body motion is defined as a Born rigid body motion carried out under the kinematic restrictions of special relativity. A relativistic Born rigid body motion requires a specific program of forces acting on the different volume elements of the body during its acceleration. For an accelerated motion which can be also performed as a relativistic Born rigid body motion, stresses created by the relativistic contraction effect cannot be separated from stresses created otherwise. According to a theorem by Herglotz [7] and Noether [8] all accelerations not involving rotation can always be performed as relativistic Born rigid body motions, whereas all those involving rotation do violate the requirements for such motions. Motions involving rotation are therefore capable of breaking the interaction symmetry with the ether, which in Poincaré's view is the reason for our inability to observe an absolute motion.

Experiments involving rotating atoms, nuclei and elementary particles, are most likely unsuitable to observe relativity-violating effects, because there the time needed for the Fitzgerald-Lorentz contraction to take place is extremely short. A very different situation arises for macroscopic bodies, where the contraction time is determined by the speed of elastic waves. Since it is difficult to bring macroscopic bodies to relativistic velocities, we depend on the comparatively small velocity of the earth through the ether. If this velocity is equal to the measured velocity  $v \simeq 300$  km/sec of the earth against the microwave background, one has for the ratio  $v/c \simeq 10^{-3}$ , with relativity-violating effects depending on the much smaller ratio  $v^2/c^2 \simeq 10^{-6}$ .

As the most simple example we consider a rod moving with the absolute velocity  $v$  and which at the same time rotates perpendicular to the rod axis and the direction of  $v$ . If the rotation is slow, to assure that the rod has in each moment sufficient time to undergo a Fitzgerald-Lorentz contraction, an observer at rest with the ether would see that the rod periodically contracts and expands by the ratio  $\sqrt{1-v^2/c^2}$ , whereas for a co-moving (non-rotating) observer, it would always show the same length, regardless of its orientation, because all the measuring sticks of the observer would be contracted in exactly the same way. However, if the rotation is very fast, with the rotational speed comparable to the speed of stress waves in it, the Lorentz-Poincaré theory predicts a departure from this behaviour, because there the Fitzgerald-Lorentz contraction would take a time comparable to the time the rod needs to change its orientation relative to the direction of  $v$ . Therefore, for a rapidly rotating rod the Lorentz-Poincaré theory would even predict for a co-moving observer a periodic change in the length of the rod, whereas in Einstein's theory no such change in its length would take place.

The velocity of elastic waves in a solid is of the order  $a \simeq \sqrt{E/\rho}$ , where  $E$  is the Young module and  $\rho$  the density of the solid. For all solids of interest the tensile strength  $\sigma$  is by about 2 orders of magnitude smaller than the Young module. The maximum rotational velocity attainable  $v_{\text{rot}}^{\text{max}} \simeq \sqrt{\sigma/\rho}$ , and at which the rod would break, therefore falls short by more than one order of magnitude of the desired velocity of stress waves. As a result, the predicted relativity-violating effects are probably much too small to be observable, and for this reason experiments [9, 10] proposed along these lines are not very promising.

A very different situation exists, if the time for the deformations to take place is determined by elastic bending waves [11]. The bending wave of a rod with the length  $l$  and radius  $r$ , fixed at one of its ends, has a circular frequency given by

$$\omega_0 \simeq 1.76 (r/l^2) \sqrt{E/\rho}. \quad (1)$$

The velocity of the bending wave is  $a \simeq (r/l) \sqrt{E/\rho}$ . The condition to make  $a \lesssim v_{\text{rot}}^{\text{max}}$ , which is to prevent mechanical rupture, is there  $l/r > \sqrt{E/\rho} \simeq 10$ .

To use bending waves for possible relativity-violating effects we consider a rotating rectangular cross in an earth-fixed laboratory. The cross shall

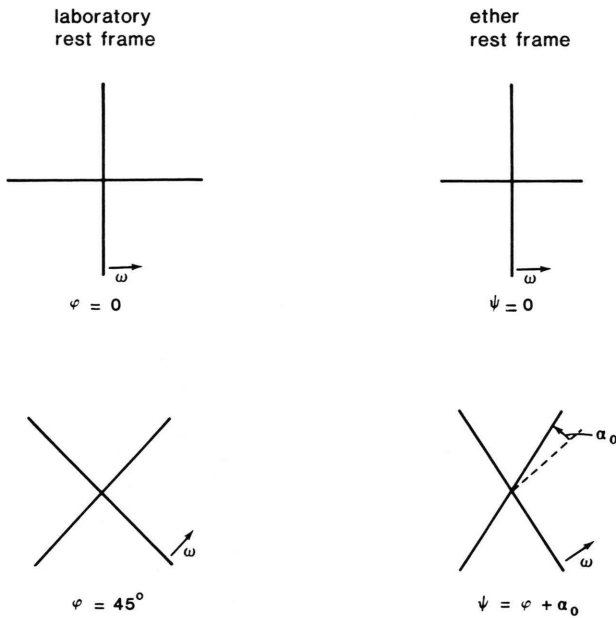


Fig. 1. The shape of a slowly rotating cross in a laboratory frame (left column) and in a frame at rest with the ether (right column) for two different orientations of the cross given by the angle  $\varphi = 0$  and  $\varphi = 45^\circ$ . The cross moves along the direction  $\varphi = 0$ , with the axis of rotation perpendicular to the direction of its motion against the ether. If the rotation is sufficiently slow, the shape of the cross is determined by the Lorentz-transformation, with both (the Lorentz-Poincaré and Einstein) theories giving the same result. (Instead of the presumed small earth-velocity  $v = 300$  km/sec against the ether, the picture is drawn for  $v = 0.7 c$ ).

have four equal arms of length  $l$  and radius  $r$ . According to the Lorentz-Poincaré theory the cross is moving with the absolute velocity  $v \simeq 300$  km/sec against the substratum. If we let the cross *slowly* spin around its axis with the direction of rotation perpendicular to  $v$ , it would appear, for two different observers as shown in Figure 1: One in the rest frame of the cross, and the other in the rest frame of the ether, depicting two different orientations of the cross, at a right angle and  $45^\circ$  to the direction of  $v$ .

We introduce a two-dimensional Cartesian coordinate system centered in the cross and in its plane, with the  $x$ -axis directed along  $v$ . The orientation of one arm of the cross is shown in Figure 2. If the cross does not rotate, both the Einstein and Lorentz-Poincaré theories will give identical results. The relativistic contraction effect will lead to a different angle under which the arm of the cross ap-

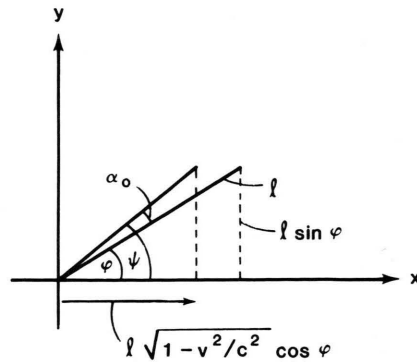


Fig. 2. The projections  $l \sin \varphi$  and  $l \cos \varphi$  along the  $y$  and  $x$  axis, of one arm of the cross with the length  $l$  in a co-moving reference system. In a system at rest with the ether against which the cross moves along the  $x$ -axis with the velocity  $v$ , the projection along the  $y$ -axis remains unchanged but the projection along the  $x$ -axis is reduced by the factor  $\sqrt{1 - v^2/c^2}$ ; consequently, the angle of inclination of the arm against the  $x$ -axis, which if measured in a co-moving system is  $\varphi$ , is in a system at rest with the ether seen under the angle  $\psi = \varphi + \alpha$ .

pears in a system at rest with the cross and one at rest with the ether. If in the first system the angle the arm makes with the  $x$ -axis is  $\varphi$  and in the second system  $\psi$  then both are related to each other by

$$\operatorname{tg} \varphi = \gamma \operatorname{tg} \psi, \quad \gamma \equiv 1/\sqrt{1 - v^2/c^2}. \quad (2)$$

Putting  $\psi = \varphi + \alpha$ , where the angle  $\alpha$  is a measure of the distortion the cross suffers, and assuming that  $\alpha \ll 1$  one can put  $\operatorname{tg}(\varphi + \alpha) \simeq (\operatorname{tg} \varphi + \alpha)/(1 - \alpha \operatorname{tg} \varphi)$ , and hence

$$\alpha \simeq \frac{(\gamma - 1) \operatorname{tg} \varphi}{1 + \gamma \operatorname{tg}^2 \varphi}. \quad (3)$$

For  $v \simeq 300$  km/sec,  $\gamma \simeq 1$ , and one can put  $1 + \gamma \operatorname{tg}^2 \varphi \simeq 1 + \operatorname{tg}^2 \varphi = 1/\cos^2 \varphi$ . Hence

$$\alpha \simeq ((\gamma - 1)/2) \sin 2\varphi \simeq (1/4) (v^2/c^2) \sin 2\varphi. \quad (4)$$

In case special relativity is valid one has to put  $\varphi = \omega t$ , and obtains

$$\alpha(t) = \alpha_0(t) \simeq (1/4) (v^2/c^2) \sin(2\omega t). \quad (5)$$

In the Lorentz-Poincaré theory  $\alpha(t) = \alpha_0(t)$  is only valid in the limit of infinitely slow rotation, whereas for fast rotation it is determined by the differential equation

$$\ddot{\alpha} + 2\omega_1 \dot{\alpha} + \omega_0^2 \alpha = (1/4) (v^2/c^2) \omega_0^2 \sin(2\omega t). \quad (6)$$

In this equation,  $\omega_0$  is the circular frequency of the bending waves given by (1);  $\omega_1$  is a damping constant given by [11]

$$\omega_1 \simeq \frac{2}{9} \frac{\chi T \varepsilon^2 E}{r^2 Q c_p}, \quad (7)$$

where  $\chi$  is the heat conduction coefficient,  $T$  the absolute temperature,  $\varepsilon$  the thermal expansion coefficient,  $c_p$  the constant pressure specific heat, and  $r$  and  $E$  as defined above. Inserting numerical values, one finds for substances of interest that  $\omega_1 \ll \omega$ .

The solution of (6) is given by

$$\alpha(t) = A \sin(2\omega t + \delta), \quad (8)$$

where

$$A = \frac{(1/4)(v^2/c^2)\omega_0^2}{\sqrt{(\omega_0^2 - 4\omega^2)^2 + 16\omega_1^2\omega^2}}, \quad (9)$$

$$\operatorname{tg} 2\delta = -\frac{4\omega_2\omega}{\omega_0^2 - 4\omega^2}. \quad (10)$$

For  $\omega_1 \ll \omega_0$  the amplitude has a sharp resonance at  $\omega \simeq \omega_0/2$ , for which

$$A = A_{\text{res}} \simeq (1/8)(v^2/c^2)(\omega_0/\omega_1), \quad (11)$$

$$\delta = \delta_{\text{res}} \simeq -\pi/4. \quad (12)$$

The half-width of the resonance is

$$\Delta\omega \simeq \omega_1/2. \quad (13)$$

At resonance, the distortion angle  $\alpha$  has a maximum, with a phase shift of  $45^\circ$  lagging behind the special relativistic distortion  $\alpha_0$ , and is given by

$$\alpha = \alpha_{\text{res}}(t) \simeq (1/8)(v^2/c^2)(\omega_0/\omega_1) \sin(2\omega t - \pi/2). \quad (14)$$

For  $\omega \ll \omega_0/2$ , well below the resonance, and assuming as before that  $\omega_1 \ll \omega_0$ , one has

$$\delta_- \simeq 0, \quad (15)$$

$$\alpha_-(t) \simeq (1/4)(v^2/c^2)(\omega_0^2/(\omega_0^2 - 4\omega^2)) \sin(2\omega t). \quad (16)$$

For  $\omega \gg \omega_0$ , well above the resonance, one has

$$\delta_+ \simeq -\pi/2, \quad (17)$$

$$\alpha_+(t) \simeq (1/4)(v^2/c^2)(\omega_0^2/(\omega_0^2 - 4\omega^2)) \cdot \sin(2\omega t - \pi/2). \quad (18)$$

An observer moving along the rotating cross can, of course, only measure the difference  $\delta\alpha = \alpha(t) -$

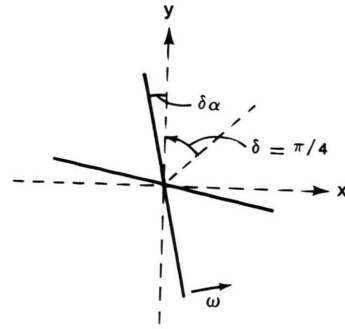


Fig. 3. Maximum angular distortion of rotating cross at resonance as it would appear according to the Lorentz-Poincaré theory in a co-moving system. The distortion is due to slow moving bending waves (no appreciable change in the length of the rod, for which the much faster compression waves would be responsible, does occur).

$\alpha_0(t)$ . Special relativity would be confirmed only if  $\delta\alpha = 0$ .

At resonance  $\omega \simeq \omega_0/2$ , one has

$$\delta\alpha_{\text{res}} = (1/4)(v^2/c^2) \cdot [(\omega_0/2\omega_1) \sin(2\omega t - \pi/2) - \sin(2\omega t)]. \quad (19)$$

The factor  $\omega_0/\omega_1$  is normally very large and the second term in the bracket of (19) can therefore be neglected. This means that at resonance  $\delta\alpha_{\text{res}} \simeq \alpha_{\text{res}}$ . Putting  $\omega t = \varphi$ , we have

$$\delta\alpha_{\text{res}} \simeq (1/8)(v^2/c^2)(\omega_0/\omega_1) \sin(2\varphi - \pi/2). \quad (20)$$

The maximum observable distortion, shown in Fig. 3, occurs at  $\varphi = 90^\circ$ .

Below the resonance, for  $\omega \ll \omega_0/2$ , one has

$$\begin{aligned} \delta\alpha_- &\simeq (v^2/c^2)(\omega^2/(\omega_0^2 - 4\omega^2)) \sin(2\omega t) \\ &\rightarrow (v^2/c^2)(\omega^2/\omega_0^2) \sin(2\omega t) \\ &\simeq (v^2/c^2)(\omega^2/\omega_0^2) \sin 2\varphi, \end{aligned} \quad (21)$$

in phase with  $\alpha_0(t)$ . Well above the resonance, for  $\omega \gg \omega_0$  and for  $\omega \rightarrow \infty$  one has

$$\begin{aligned} \delta\alpha_+ &\simeq -(1/4)(v^2/c^2) \sin(2\omega t) \\ &\simeq -(1/4)(v^2/c^2) \sin 2\varphi, \end{aligned} \quad (22)$$

in opposite phase to  $\alpha_0(t)$ .

As an example, we assume a cross made from steel with  $l = 10$  cm, and  $r = 0.5$  cm. We find  $\omega_0 \simeq 4.6 \times 10^3 \text{ sec}^{-1}$ ,  $\omega_1 \simeq 5 \times 10^{-3} \text{ sec}^{-1}$ , and hence  $\omega_0/\omega_1 \simeq 10^6$ . For  $v = 300$  km/sec, we find  $\delta\alpha_{\text{res}}^{\text{max}} \sim 1/8$ , and for the maximum displacement at the end of

one arm,  $\delta x_{\max} \sim l \delta \alpha_{\text{res}}^{\max} \sim 1$  cm. The predicted effect is so large that the linear elasticity theory no longer applies. Under these circumstances the value of  $\omega_1$  is probably much larger and  $\omega_0$  smaller. But in any case, a large effect is predicted and which should be easily observable.

Below the resonance, for example, if  $\omega = \omega_0/10$  one finds  $\delta \alpha_{\text{res}}^{\max} \simeq 10^{-8}$ , and above the resonance  $\delta \alpha_{\text{res}}^{\max} \simeq -2.5 \times 10^{-7}$ .

At resonance the tangential speed of the arms are  $v_{\text{rot}} = l \omega = l \omega_0/2 \simeq 250$  meters/second, comparable to the speed of an ultracentrifuge.

## Appendix

The first computation of the contraction effect by Lorentz [4] on the basis of the ether theory was done under the very restrictive assumption of electrostatic forces. A more general argument was given by Jannossy [3] citing the well-known retarded potential solutions for point charges [12], which without any reference to special relativity show that the deformation of the equipotential surfaces is exactly given the factor  $\sqrt{1-v^2/c^2}$ . We will present here a derivation which shows more directly the underlying cause of the contraction effect.

According to the view of Lorentz and Poincaré the contraction effect can be accounted for by the Lorentz-transformations, but it must by itself be derived from the interaction of a moving body with the ether. The Maxwell's equations will be certainly correct in a system at rest with the ether, and therefore also correct for a body at rest with the ether. Instead of Maxwell's equations one can use the equations for the scalar and vector potentials [13] (in electrostatic cgs units):

$$\begin{aligned} -\frac{1}{c^2} \frac{\partial^2 \Phi}{\partial t^2} + \nabla^2 \Phi &= -4\pi \varrho(\mathbf{r}, t), \\ -\frac{1}{c^2} \frac{\partial^2 \mathbf{A}}{\partial t^2} + \nabla^2 \mathbf{A} &= -(4\pi/c) \mathbf{j}(\mathbf{r}, t) \end{aligned} \quad (\text{A. 1})$$

$$\begin{aligned} -\frac{1}{c^2} \frac{\partial^2 \Phi'}{\partial t'^2} + \left(1 - \frac{v^2}{c^2}\right) \frac{\partial^2 \Phi'}{\partial x'^2} + \frac{\partial^2 \Phi'}{\partial y'^2} + \frac{\partial^2 \Phi'}{\partial z'^2} &= -4\pi \varrho(\mathbf{r}', t'), \\ -\frac{1}{c^2} \frac{\partial^2 \mathbf{A}'}{\partial t'^2} + \left(1 - \frac{v^2}{c^2}\right) \frac{\partial^2 \mathbf{A}'}{\partial x'^2} + \frac{\partial^2 \mathbf{A}'}{\partial y'^2} + \frac{\partial^2 \mathbf{A}'}{\partial z'^2} &= -(4\pi/c) \mathbf{j}(\mathbf{r}', t'), \\ -\frac{1}{c^2} \frac{\partial^2 \mathbf{A}'}{\partial t'^2} + \left(1 - \frac{v^2}{c^2}\right) \frac{\partial^2 \mathbf{A}'}{\partial x'^2} + \frac{\partial^2 \mathbf{A}'}{\partial y'^2} + \frac{\partial^2 \mathbf{A}'}{\partial z'^2} &= 0. \end{aligned} \quad (\text{A. 8})$$

to be supplemented by the invariance under gauge transformations

$$\begin{aligned} \Phi &\rightarrow \Phi - \frac{1}{c} \frac{\partial \Lambda}{\partial t}, \\ \mathbf{A} &\rightarrow \mathbf{A} + \nabla \Lambda, \end{aligned} \quad (\text{A. 2})$$

where for Lorentz gauge, the function  $\Lambda$  satisfies the wave equation

$$-\frac{1}{c^2} \frac{\partial^2 \Lambda}{\partial t^2} + \nabla^2 \Lambda = 0. \quad (\text{A. 3})$$

After  $\Phi$  and  $\mathbf{A}$  have been computed from these sets of equations, the electric and magnetic fields are given by

$$\mathbf{E} = -\nabla \Phi - \frac{1}{c} \frac{\partial \mathbf{A}}{\partial t}, \quad \mathbf{H} = \nabla \times \mathbf{A}. \quad (\text{A. 4})$$

For a solid body at rest in the ether and in a static equilibrium, and having in it some charge and current distribution we have

$$\begin{aligned} \nabla^2 \Phi &= -4\pi \varrho(\mathbf{r}), \\ \nabla^2 \mathbf{A} &= -(4\pi/c) \mathbf{j}(\mathbf{r}), \quad \nabla^2 \Lambda = 0. \end{aligned} \quad (\text{A. 5})$$

For a given charge and electric current distribution, the potentials  $\Phi$  and  $\mathbf{A}$  can be computed by an integration over the solid body with the result

$$\Phi = \int \frac{\varrho(\mathbf{r}^*)}{|\mathbf{r} - \mathbf{r}^*|} d\mathbf{r}^*, \quad \mathbf{A} = \frac{1}{c} \int \frac{\mathbf{j}(\mathbf{r}^*)}{|\mathbf{r} - \mathbf{r}^*|} d\mathbf{r}^*. \quad (\text{A. 6})$$

If we now set the body in motion with the absolute velocity  $v$  against the ether rest frame, we make the Galilei-transformation

$$x' = x - vt, \quad y' = y, \quad z' = z, \quad t' = t, \quad (\text{A. 7})$$

where  $x'$ ,  $y'$ ,  $z'$ , and  $t'$  are measured in a frame moving with the body.

In carrying out these transformations with regard to (A. 1) and (A. 3), the scalar and vector potentials change from  $\Phi$  to  $\Phi'$ ,  $\mathbf{A}$  to  $\mathbf{A}'$ , and  $\Lambda$  to  $\Lambda'$ . The result is:

We now specialize (A. 8) to the limiting situation, where a new equilibrium state has been established within the solid body after it has been accelerated to the absolute velocity  $v$ . If a new state of equilibrium has been established, one has to put  $\partial/\partial t' = 0$ . Furthermore, according to (A. 7) we can put everywhere  $y' = y$  and  $z' = z$ . The result on (A. 8) is

$$\begin{aligned} \left(1 - \frac{v^2}{c^2}\right) \frac{\partial^2 \Phi'}{\partial x'^2} + \frac{\partial^2 \Phi'}{\partial y^2} + \frac{\partial^2 \Phi'}{\partial z^2} &= -4\pi \varrho(x', y, z), \\ \left(1 - \frac{v^2}{c^2}\right) \frac{\partial^2 A'}{\partial x'^2} + \frac{\partial^2 A'}{\partial y^2} + \frac{\partial^2 A'}{\partial z^2} &= -(4\pi/c) j(x', y, z), \\ \left(1 - \frac{v^2}{c^2}\right) \frac{\partial^2 A'}{\partial x'^2} + \frac{\partial^2 A'}{\partial y^2} + \frac{\partial^2 A'}{\partial z^2} &= 0. \end{aligned} \quad (\text{A. 9})$$

Comparing (A. 5) with (A. 9), we immediately see that

$$\Phi' = \Phi, \quad A' = A, \quad A' = A, \quad (\text{A. 10})$$

provided we put everywhere

$$dx' = dx \sqrt{1 - v^2/c^2}. \quad (\text{A. 11})$$

This means that if the body is contracted by the factor  $\sqrt{1 - v^2/c^2}$ , then exactly the same equations for  $\Phi$ ,  $A$  and  $A$  result as for the case where the body was at rest in the ether. This shows that the Fitz-

gerald-Lorentz contraction given by (A. 11) will leave the electromagnetic equations invariant because the moving body carries its charges and currents along. Or differently expressed, the computation of the scalar and vector potential in any inertial reference frame at rest with the body cannot reveal the absolute motion of the body, since the person carrying out the computation and comparing the result with the observation is using measuring rods which too suffer a Fitzgerald-Lorentz contraction.

The factor  $(1 - v^2/c^2)$  appearing in (A. 8) and (A. 9) can also be qualitatively understood as resulting from the Doppler effect of two electric point charges moving behind each other through the ether [14]. The charge in front receives a flux of virtual photons, responsible for the interaction, reduced by the factor  $(1 - v/c)$ , and likewise the charge behind receives a flux larger by the factor  $(1 + v/c)$ . The Coulomb force acting between both charges would therefore be changed from  $e^2/r^2$  to  $e(1 - v/c) \times e(1 + v/c)/r^2 = (1 - v^2/c^2) e^2/r^2$ , and the force would be the same at a new equilibrium distance  $r' = r \sqrt{1 - v^2/c^2}$ . The Doppler-effect as being the underlying cause, also coincides with the view of Voigt [15], who already almost 100 years ago derived special Lorentz transformations, starting solely from the Doppler principle.

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